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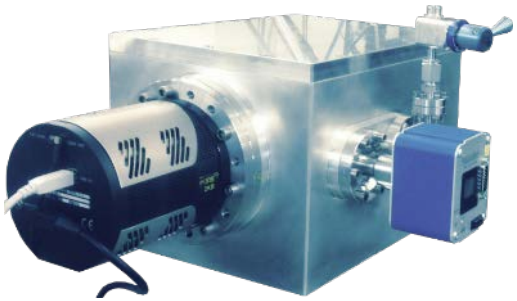
FOM



# *Broadband spectroscopy of EUV light sources using a transmission grating spectrometer*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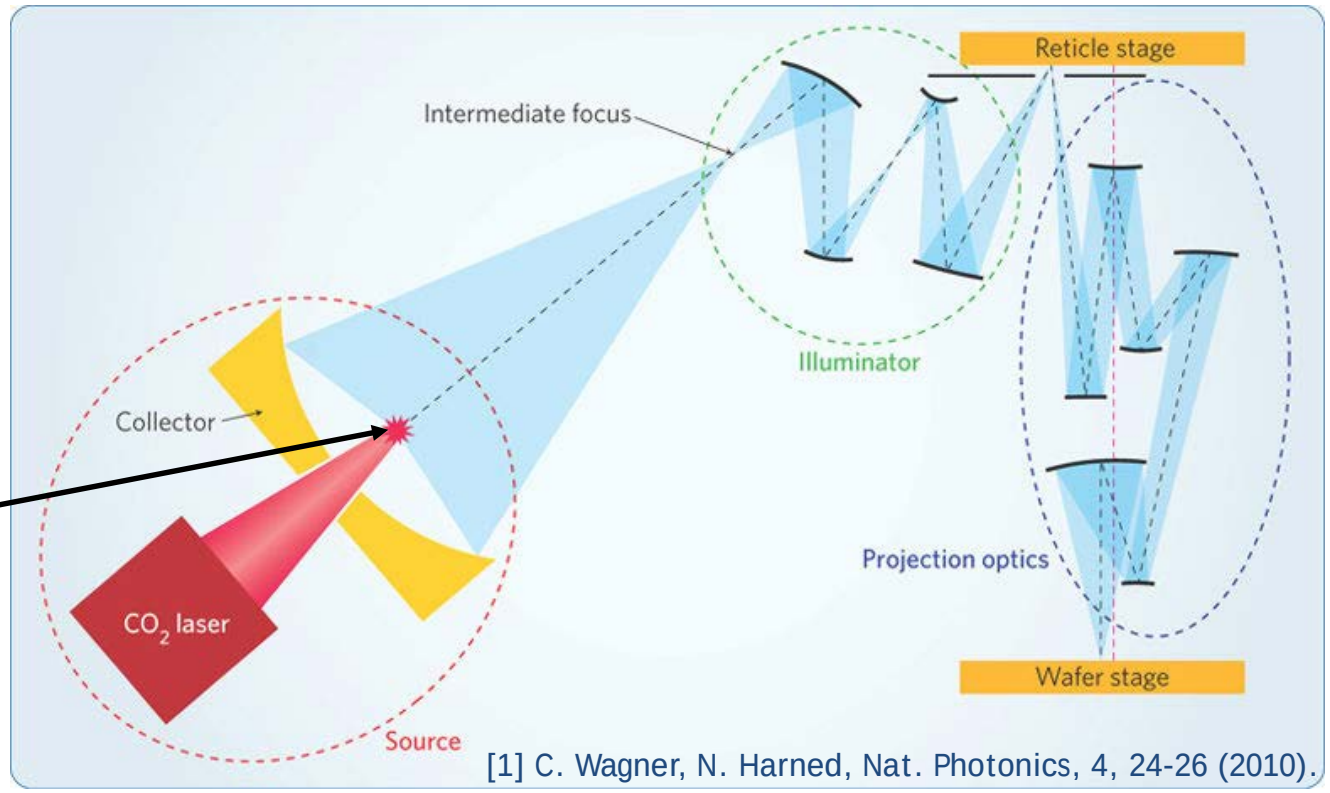
XLIV OPTICS

# Outline

- ✓ Motivation
- ✓ XUV transmission grating spectrometer
- ✓ Nd:YAG and $CO_2$ laser driven plasmas
  - 1- EUV measurements
  - 2- DUV-NIR measurements
- ✓ Conclusions & outlook

# Motivation

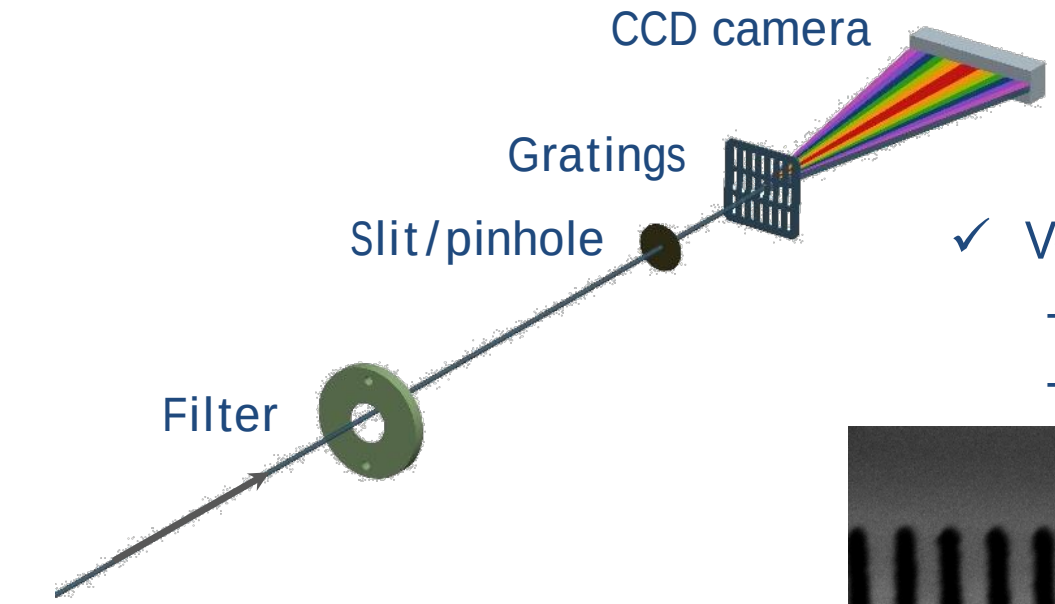
EUV emitting plasma

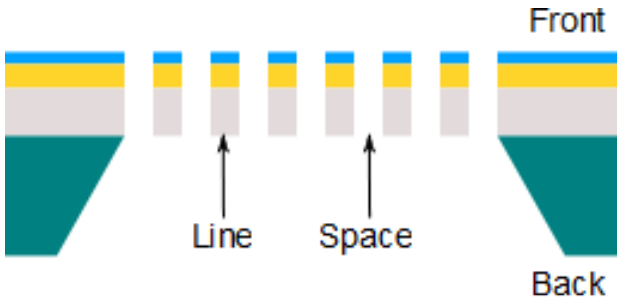



[1] C. Wagner, N. Harned, Nat. Photonics, 4, 24-26 (2010).

- ✓ Useful light in a narrow wavelength band: 13.5 nm (±1%)
- ✓ Inherent parasitic radiation in a broad spectrum
- ✓ May cause contrast loss in patterning and heat load on optics
- ✓ Need: broadband spectral monitoring

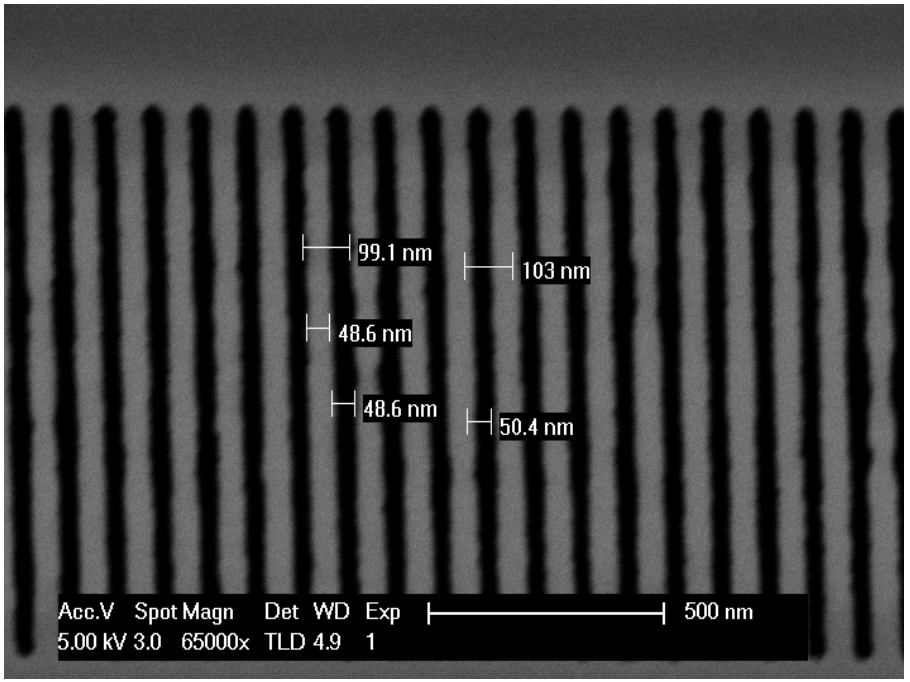
# XUV transmission grating spectrometer




Cross-section

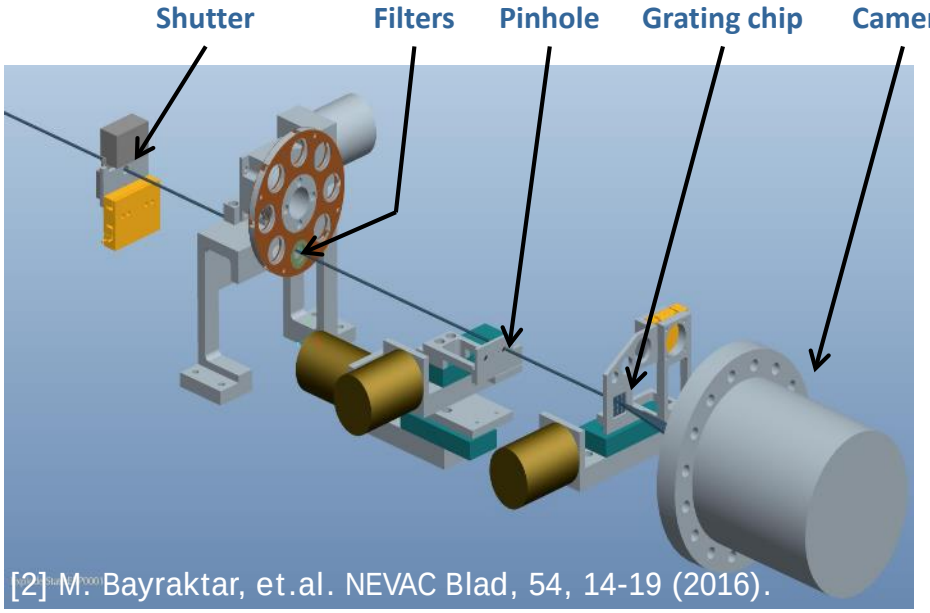
- ✓ Grating matrix
- ✓ XUV to IR range
- ✓ Very high line density
  - Up to 10.000 lines/mm
  - 0.05 nm resolution at 13.5 nm




[2] M. Bayraktar, et.al. NEVAC Blad, 54, 14-19 (2016).

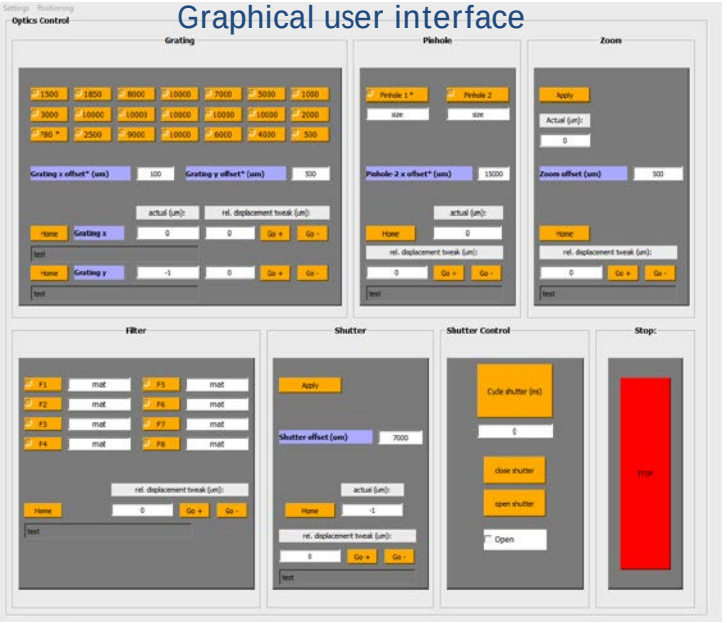
# XUV transmission grating spectrometer

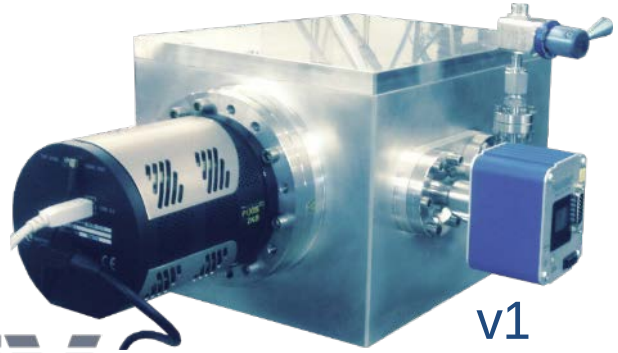
- ✓ Broadband coverage
- ✓ Compact design (~20x25x30 cm$^3$)
- ✓ Computer controlled positioning
- ✓ Straightforward alignment



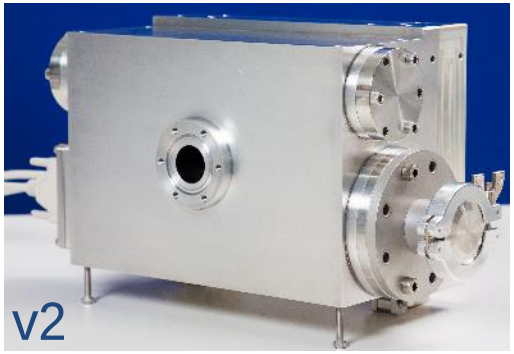

[2] M. Bayraktar, et.al. NEVAC Blad, 54, 14-19 (2016).

Graphical user interface



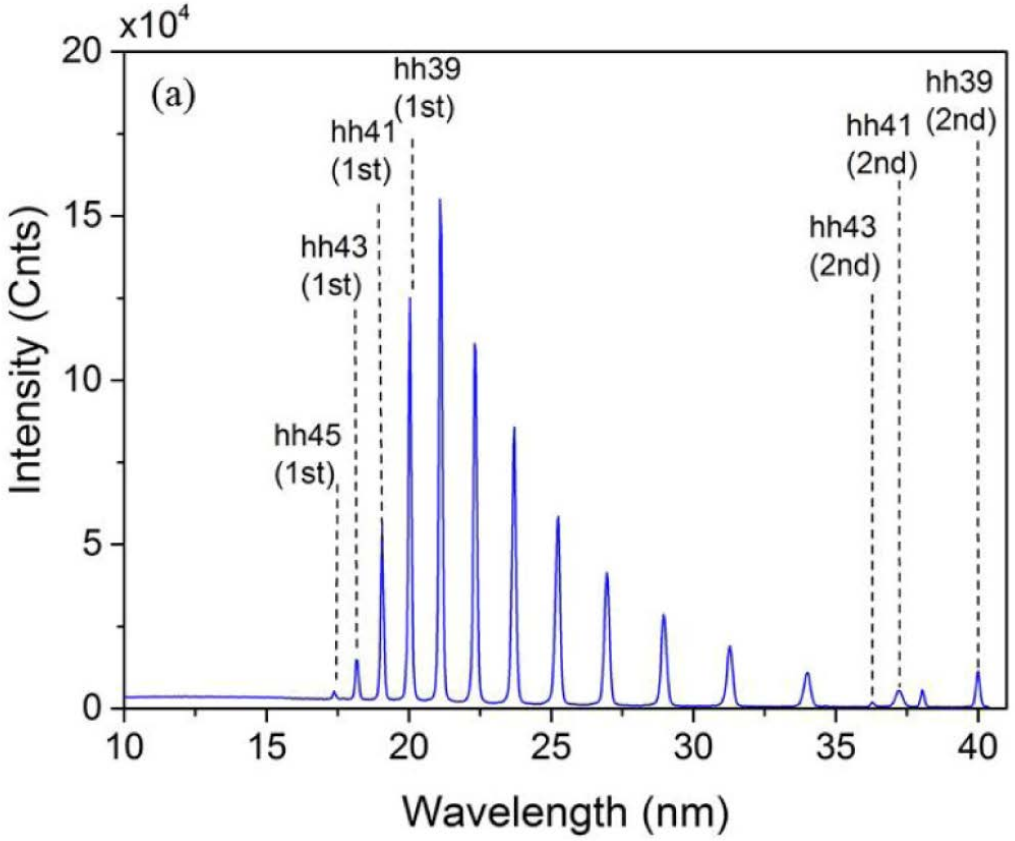



v1



v2

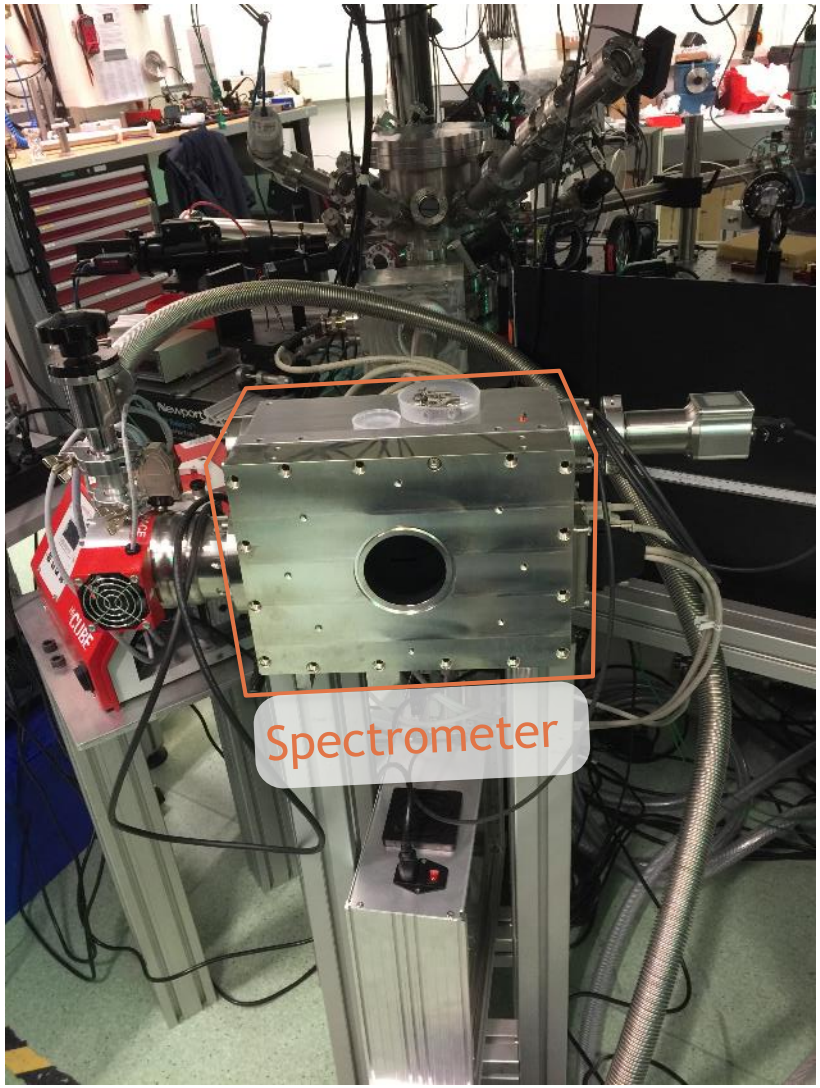
# Resolution test in a HHG source

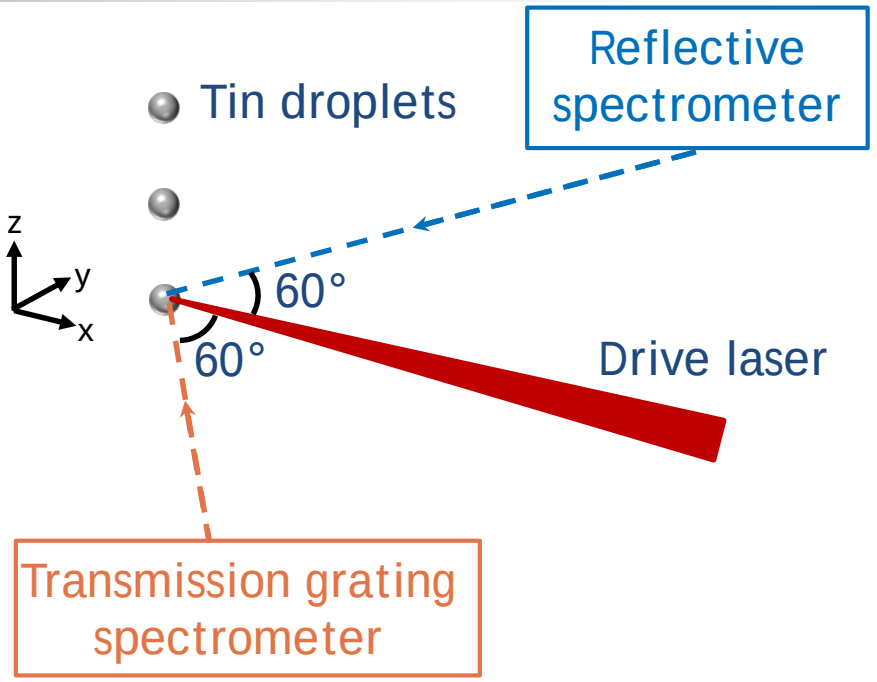



- ✓ Design resolution 0.09 nm at 21 nm (37$^{th}$ harmonic)
- ✓ Measured resolution < 0.13 nm[3]
- ✓ Can be configured for 0.05 nm resolution at 13.5 nm

[3] J. Goh et.al. Opt. Exp. 23, 4421 (2015).

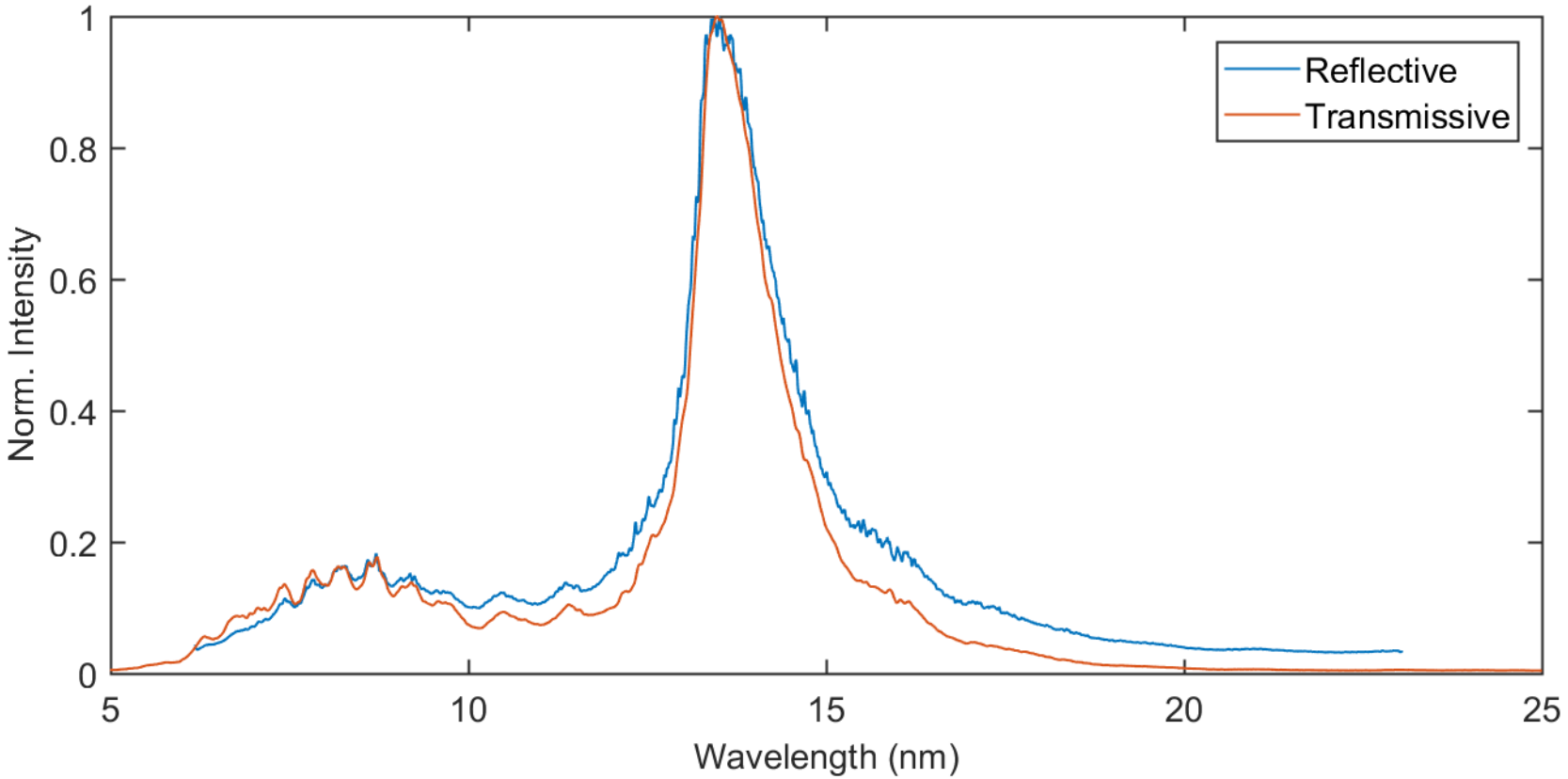
# Testing of spectrometer @ARCNL



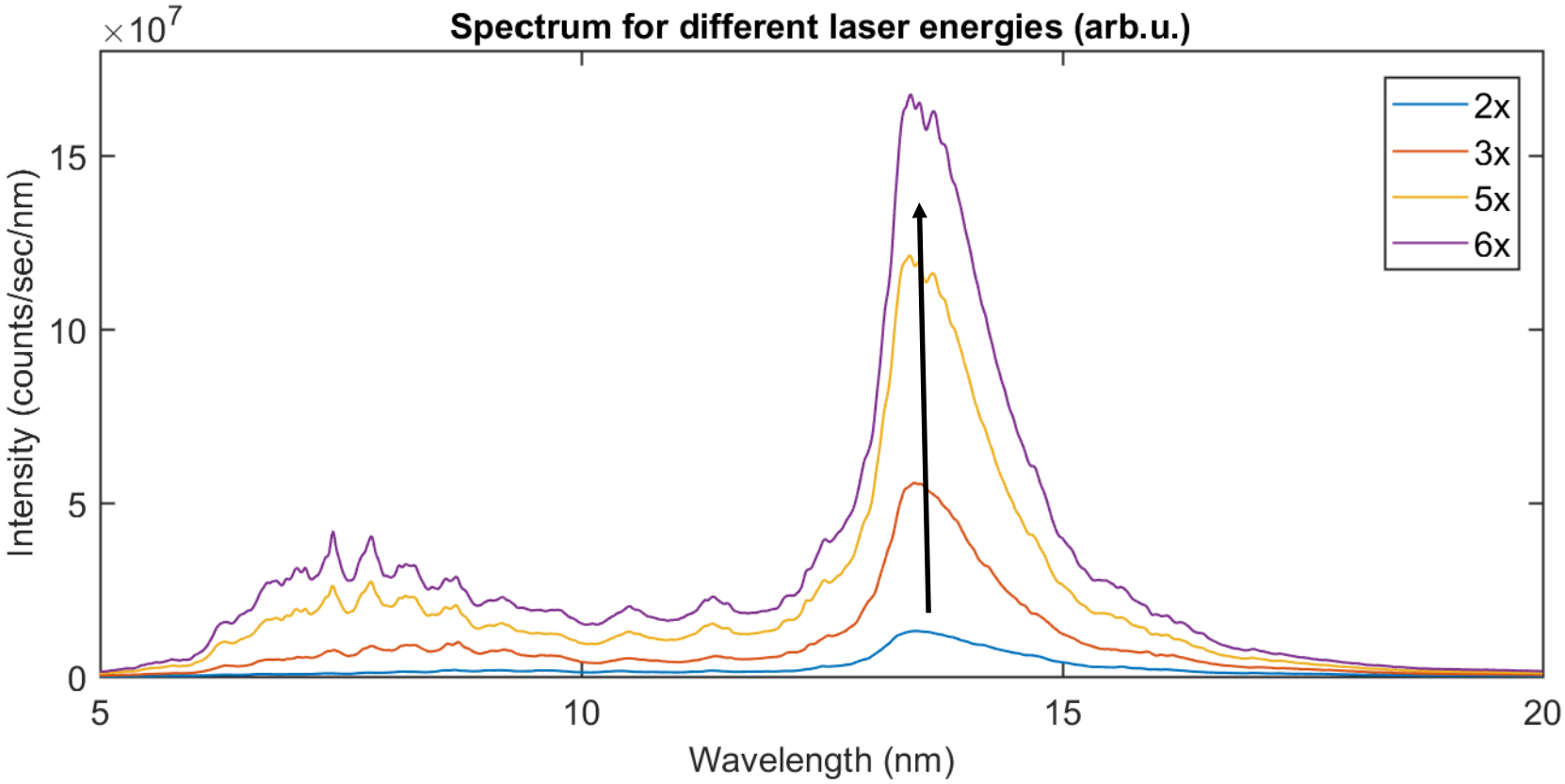

- ✓ Nd:YAG drive laser
- ✓ Gaussian pulses
- ✓ Pulse duration: 60ns
- ✓ Droplet size: ~40 µm
- ✓ Energy: 0.2 – 3 J

# Reflective vs XUV transmissive spectrometer




- ✓ Measurements with Zr filter
- ✓ Not corrected for grating efficiency → differences in intensity
- ✓ Good matching of the peaks

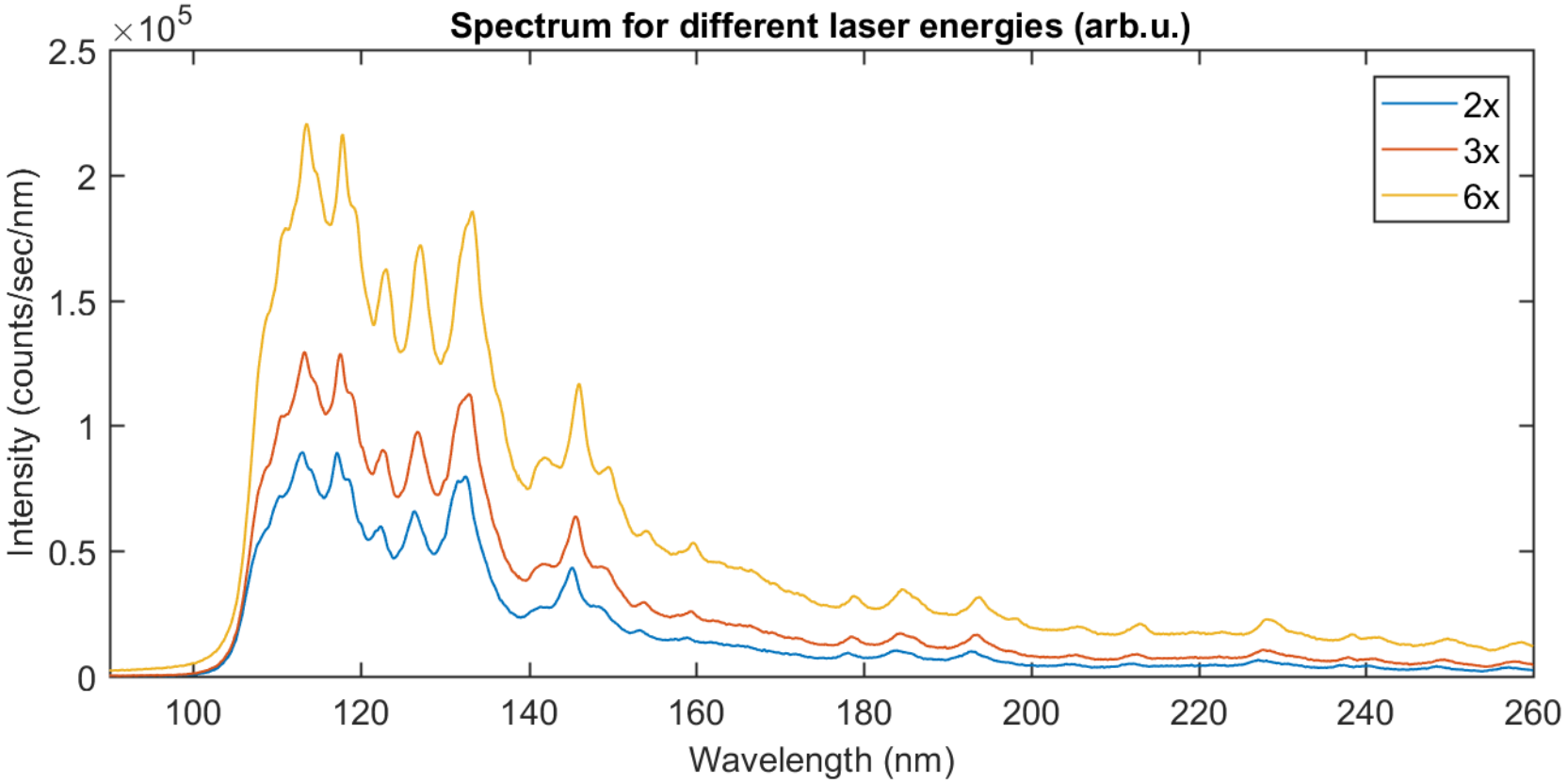
# Nd:YAG laser plasma: EUV spectra




- ✓ Measured with transmission grating spectrometer
- ✓ Increased drive laser energy → higher EUV emission
- ✓ Emission below 12 nm due to higher charge states ($Sn^{8+}$-$Sn^{15+}$)[4]

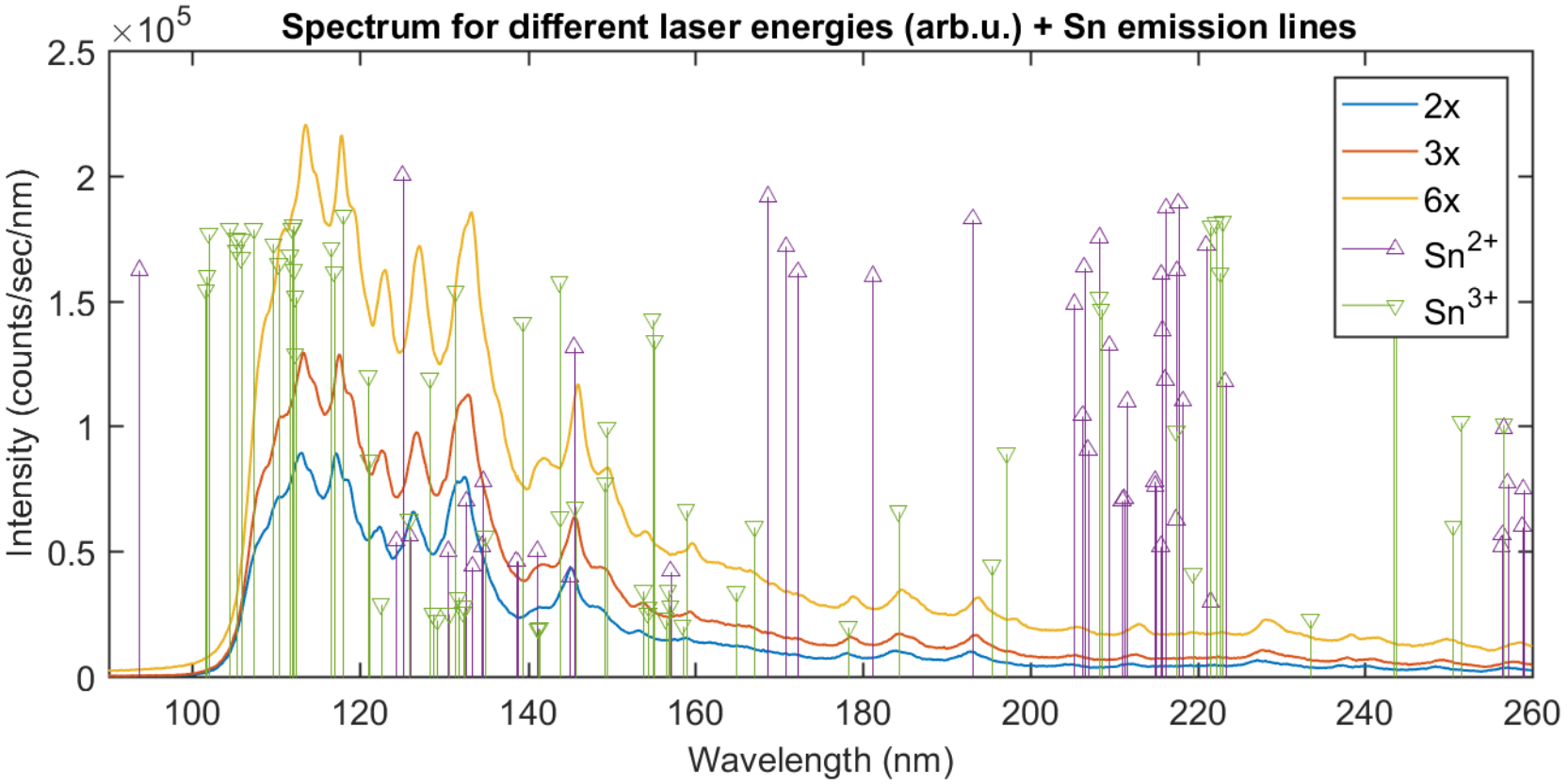
[4] F. Torretti, et.al. ArXiv: 1709.02626 (2017).

# Nd:YAG laser plasma: DUV spectra



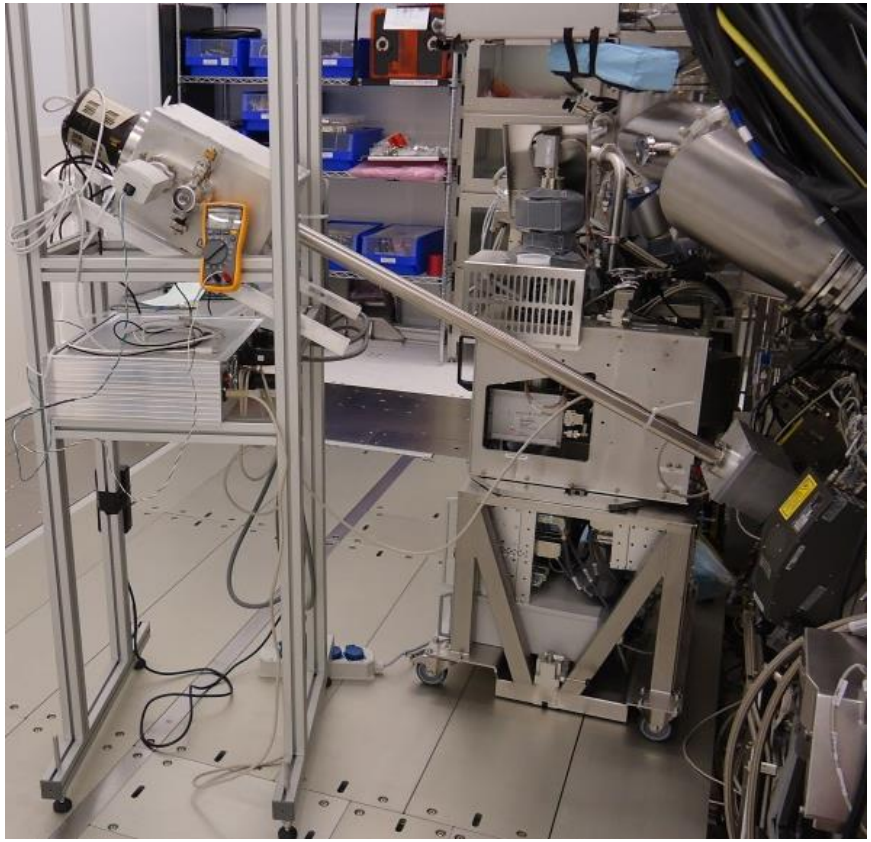

- ✓ DUV spectrum depends on plasma operating conditions
- ✓ Changes in the DUV spectrum can be traced using the spectrometer

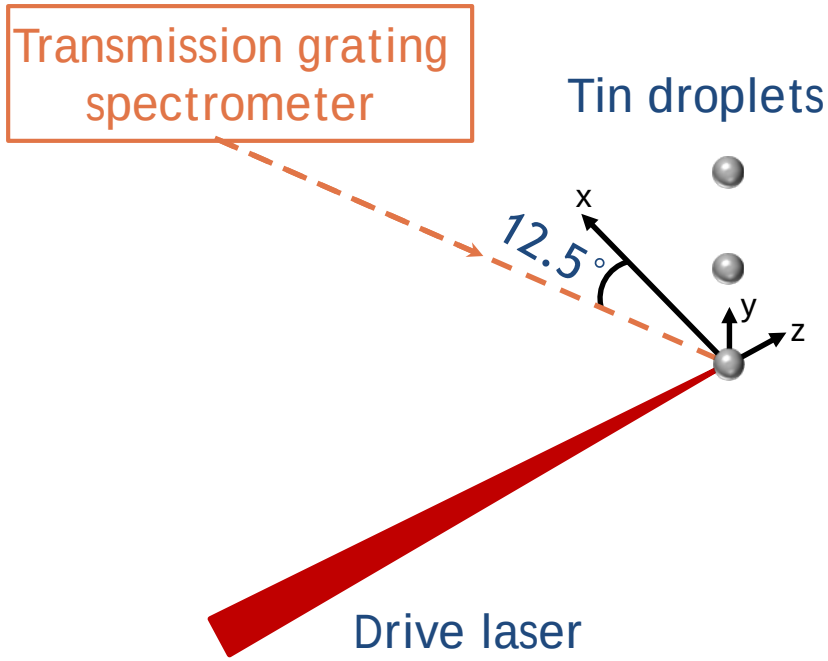
# Nd:YAG laser plasma: DUV spectra




- ✓ Reported $Sn^{+2}$ and $Sn^{+3}$ lines correlate with observed spectrum
- ✓ ARCNL and ISAN collaboration for detailed modeling

# Production EUV source

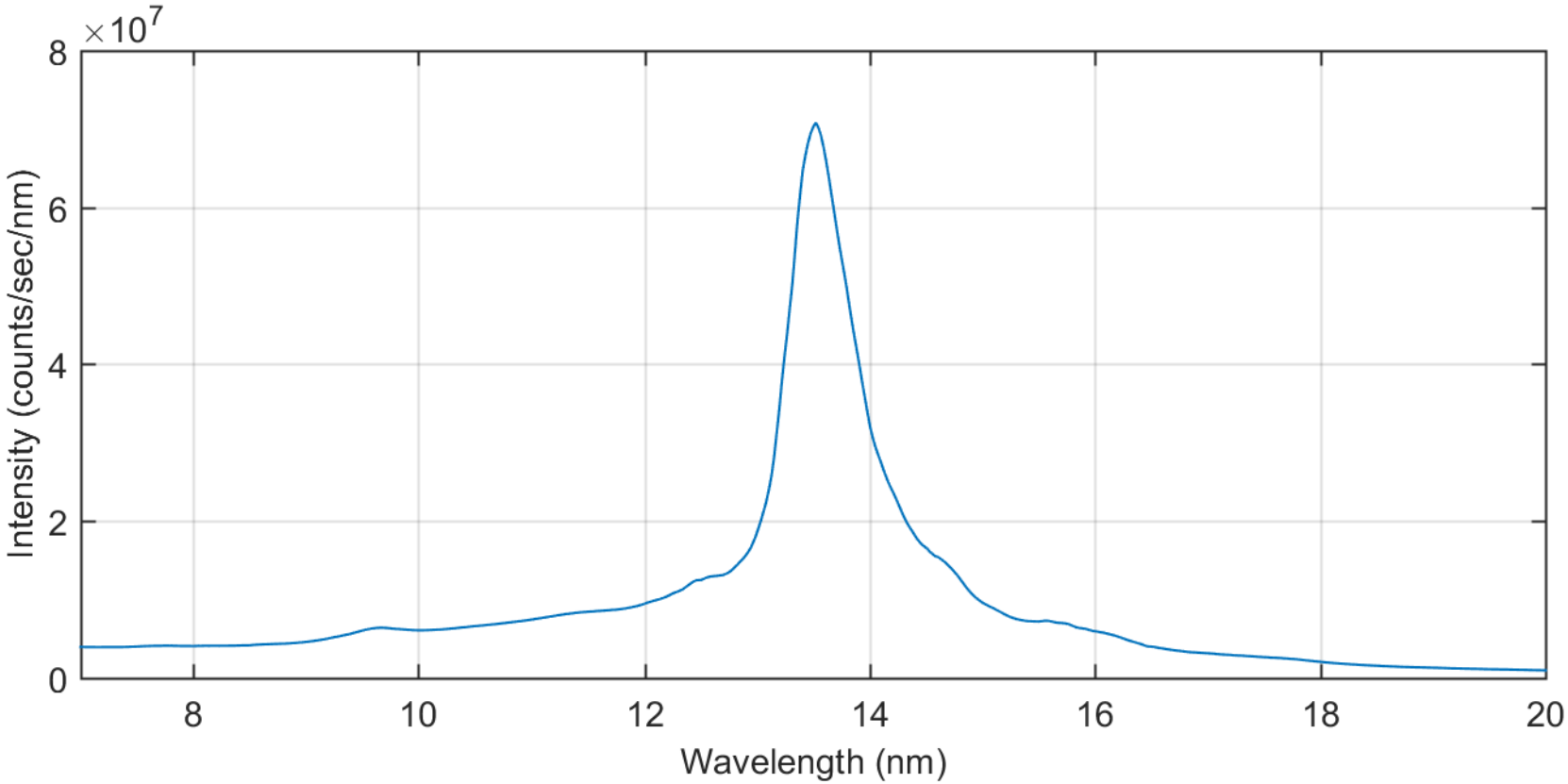





- ✓ Production EUV light source
- ✓ $CO_2$ drive laser

- ✓ Real operating conditions!
  - EUV power 120 W

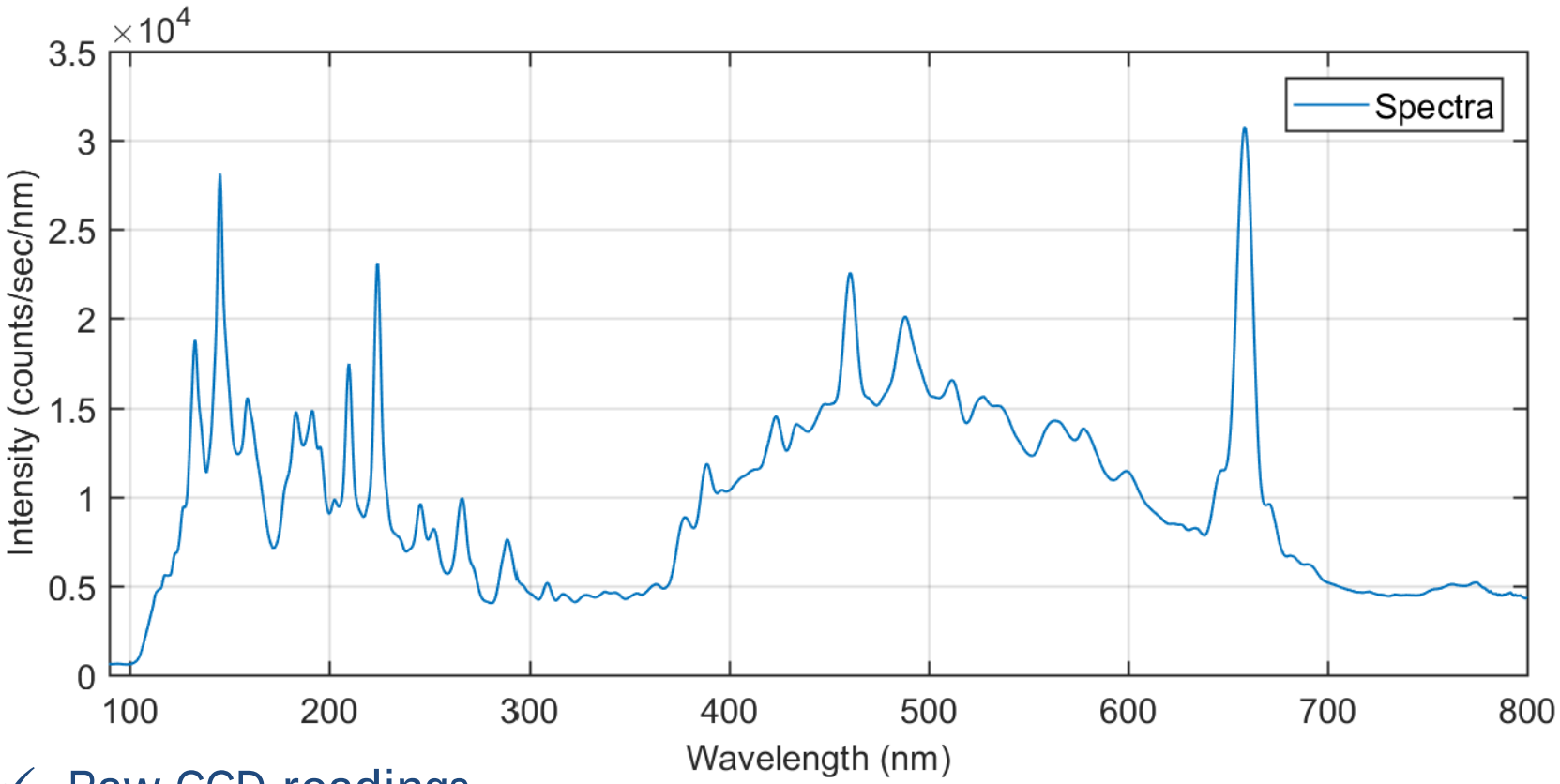
# Production EUV source




- ✓ Narrow UTA peak, mainly from $Sn^{12+}$-$Sn^{17+}$ [5]
- ✓ Intensity at lower wavelengths less pronounced
- ✓ Absolute calibration in progress

[5] K. Nishihara, et.al. Phys. Plasmas 15, 056708 (2008).

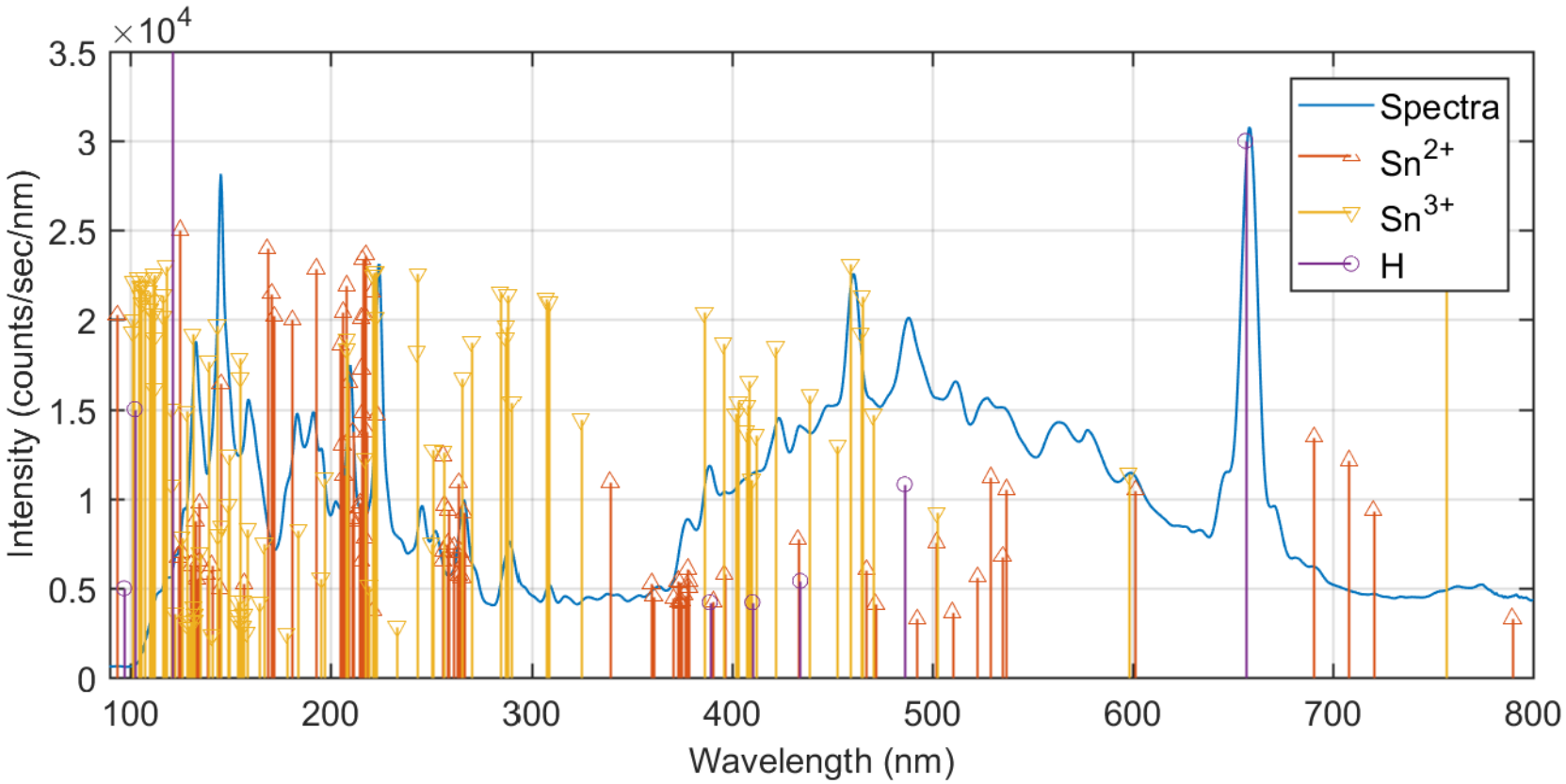
# Production EUV source: DUV-NIR spectra




- ✓ Raw CCD readings
- ✓ Low but detectable DUV-NIR intensity
- ✓ Previous knowledge: DUV is ~0.3% of EUV light in resist level[6]
- ✓ Absolute calibration in progress

[6] N. Davydova, et.al. SPIE, 923102 (2014).

# Production EUV source: DUV-NIR spectra




✓ $Sn^{+2}$, $Sn^{+3}$ and H lines correlate with observed spectra

# Conclusion and outlook

- ✓ 1st time spectroscopic measurement in a production EUV source
- ✓ Using a novel transmission grating spectrometer

- ✓ Spectra measured in EUV, DUV-NIR ranges from the same port

- ✓ Emission lines match with reported line positions
  - EUV UTA: $Sn^{12+}$-$Sn^{17+}$
  - EUV < 12 nm: $Sn^{8+}$-$Sn^{15+}$
  - DUV-NIR: $Sn^{2+}$-$Sn^{3+}$ and $H^{+}$

- ✓ Absolute calibration of spectrometer in progress
- ✓ Detailed plasma modeling will follow from ARCNL and ISAN to complement observed spectra and have a more complete fundamental understanding of the atomic transitions